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STRESSED WOOD CONSTRUCTION

Paper presented to the Institution, London Graduate Section, by A. E. N. Bolton. Grad I.P.E.

THIS paper is somewhat out of the general nature of matters discussed by members, and for that reason one feels rather diffident in attempting the subject at all. At any rate, an effort has been made to deal with it from the practical point of view rather than dwelling on the technicalities of the subject, and, for the same reason, figures have been omitted, except where their significance can be easily grasped.

The fact that wood is gradually being superseded by metal in many classes of industry, may have led you to expect that the term "stress" was being used to indicate the difficulties attendant on the manufacture of furniture for outsize persons, and apologies must be made here and now if a large enough field is not being covered. Justification for its limitation can be claimed solely on the grounds that the time at one's disposal negatives the possibility of amplifying the subject.

The discussion will therefore be confined to timber used in the manufacture of lightly stressed structures as produced by the aircraft industry. In this industry, again, it may be claimed that metal is rapidly superseding wood, but in defence of timber, for commercial purposes at any rate, it is still the cheapest, lightest, and most readily repairable form of construction yet devised, and for those who would argue that machines of this type are limited in size, it may be mentioned that structures built almot entirely of wood have and are being produced capable of carrying a payload equivalent to 30 passengers, crew, and baggage.

The choice of timber which can be used, is, perhaps fortunately, limited; for though there are in existence some 150,000 different species of tree, those which are mainly used are Sitka spruce; birch for the manufacture of plywood; walnut and mahogany for propeller construction. The use of ash has gradually declined mainly owing to its weight. It is still, however, considered most suitable when bent members are needed, and, being a hard wood, it is also useful for packing blocks. A good deal of space is being given to the selection and preparation of suitable timber on which the success of wood construction so largely depends. It is one of

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the few materials used nowadays which is not manufactured, and the process of its growth cannot therefore be observed. Consequently its quality must be vouched for by men of experience from the felling stage to the time when it is machined up, ready for incorporation in a structure.

The selection and structure of spruce, by far the most widely used timber for these purposes, deserves first consideration. It is obtained exclusively from a strip of territory on the Pacific Coast stretching from Oregon to Alaska, and this is, of course, its chief drawback for the manufacture of British military aircraft. It belongs to the coniferous family and is known as a banded type of tree. This name originates from the fact that the bole of the tree increases in size each year by the growth of one band, or annular ring on to the circumference.

FIG. 3. FIG. 1. FIG. 2.

In its youth the tree consists of four distinct formations (Fig. 1). Innermost is the pith centre or heart of the tree. Next is the woody structure which consists of a number of small cells separated by ducts, known as medullary rays which act as conveyers of air and food substance to the tree. Outside this is the cambium layer, being a soft resinous substance, originating from the sap, and gases

obtained from the air. This layer helps to form the new wood in the tree, the growth being far more prolific during the spring. The amount of growth in the autumn is far less but deposits of lignin tend to make it much harder and darker in appearance, with the result that by looking at the extremities of the tree, each year's growth, or "annular ring" as it is called, is easily discernible. The outside surface, is, of course, the protective skin known as the "bast" or "bark."

Were it possible, then the perfect tree would consist eventually of a heart surrounded by annular rings, each uniform and equidistant from that heart, and protected from the elements by the bark, but in practice this condition would be almost unobtainable (Fig. 2). Timber comparable with this standard, however, is grown in fairly dense forests. When completely surrounded by other trees this leafy structure tends to climb above its fellows in an effort to obtain the maximum of light, with the result that ideal specimens are sometimes found 150 to 200 ft. in height, with a bole as much as 10 ft. in diameter at the base, and quite unspoilt by branches except at the extreme top.

Timber grown on the edge of forests or open ground is seldom up to the required standard. Boughs tend to swing to the side away from the prevailing wind, the portion receiving most sun grows far more rapidly than the rest of the timber, causing twisting and unequal growth of the annular rings around the circumference. Conversely, trees surrounded by heavy undergrowth develop far too slowly and are consequently brittle, purely from under-nourishment.

Timber is always felled in the late autumn or winter when the leaves have fallen and the sap is down. Otherwise the excessive natural moisture might cause it to rot, and at best the seasoning process would be prolonged considerably. After felling they are conveyed to the sawmill either by horse or river transport, and cut up into suitable baulks for drying.

There are three ways of sawing up wood. The flat sawn method, which is never used for aircraft purposes, as there is far too great a tendency for timber cut in this way to warp, as impoverished owners of jerry built houses must know only too well. The reason for this warping is fairly easily understood if one bears in mind that in this type of sawing the plank is cut from across the full width of the tree's bole, the result being that the medullary rays, in the centre, on drying, contract in a vertical direction, whereas those at the side contract in a horizontal direction. This uneven shrinkage causes stresses to be set up and produces a curl upwards towards the extremities on the side exposed to the greater warmth.

Rift sawn timber is the best way of dissecting timber and can be most easily understood if one imagines rectangular pieces of planking

cut from the bole, in much the same way as slices are cut from a round cake. In planks of this sort the medullary rays face in practically the same direction, so that if contraction occurs, it is at least uniform. Commercially this method is not very popular, as a large percentage of the timber is wasted, and a compromise is generally made by dividing the bole into four quarters and then sawing these into planks. This compromise effects an economical utilisation of the timber while at the same time combining the advantages of the rift sawn method.

After sawing, the baulks are stacked for drying with small sticks in between each layer, so as to permit the air to flow round all four faces. The seasoning period lasts several years, depending on climatic conditions and the size of the baulks. The top layer of the stacks has to be reversed frequently, for some warping would result if one side of the timber were continually exposed to the atmosphere. When received in this country a selection of suitable baulks is made by an inspector at the docks, and if the wood were in perfect condition the moisture content should be not more than 12½ to 15%. In actual practice, is it more often 25 to 30%, being imperfectly seasoned, or shipped as deck cargo, and this fact provides the planning engineer with scope, for if he can arrange well ahead what timber will be required, the baulks can be cut up slightly oversize to the required dimensions and the drying time cut down considerably in this way.

Alternatively, the drying process may be artificially cut down to about two to three weeks by use of the kiln method, which, broadly speaking, consists of blowing hot, humid air through stacked timber and reducing the moisture content at a speed retarded only sufficiently to prevent the stresses set up damaging the fibres. It is claimed for the kiln drying method that timber properly treated in this way is just as good as that seasoned by the slower, more natural, air drying process. Actual tests have been carried out which bear out these claims, but the air drying method is still preferred whenever space and time permit. The secret of successful kiln drying is to extract the moisture uniformly from the baulk, otherwise the exterior shrinks more rapidly than the interior, the contraction of the outer fibres is resisted by the interior, with the result that in extreme cases the exterior splits badly, or at best becomes case hardened.

To maintain an even contraction throughout the baulk it is therefore necessary to be able to vary the temperature, and keep sufficient humidity in the air passing over it to avoid too rapid drying. Steam pipes are most generally used to achieve this, for the air is heated when blown by fans over them, and the atmospheric humidity can be varied by releasing the required amount of steam. For economy's sake the warm air is collected after passing over the

timber, by means of a return duct, and re-blown over the hot pipes. The humidity has increased considerably while pausing over the damp timber and this is corrected, during its passage through the return duct, by means of a trap door which allows cold air to mix with the hot. Cold air is incapable of absorbing the same quantity of moisture as hot, and the resultant mixture, when reblown over the pipes, is considerably dryer. It is impossible to regulate this influx of cold air accurately, and for that reason, more than sufficient cold air is allowed to enter the duct and the mixture flowing into the kiln is corrected to the required degree of humidity by means of steam, which is easily controlled by a valve.

The baulks of timber are stacked in the kiln in much the same way as for the air drying process, and to ensure that the moisture content is equal throughout each baulk, the temperature and humidity are first raised well above drying conditions, for a period of two hours. The drying process is then commenced by lowering the temperature and humidity in the kiln. Samples are tested frequently and, as the humidity in the timber decreases so can the temperature be raised up to a maximum of 180°F.

FIG. 4

FIG. 5.

FIG. 6.

When the moisture content of the baulks has been sufficiently reduced in the case of spruce to 12½ to 15% it is usual to raise the temperature and humidity to the maximum level for a short time. This causes the outer fibres to expand very rapidly, and neutralises any case hardening which may have taken place due to too rapid drying. When the seasoned timber is cut up ready for use, it is inspected for defects before any actual machining operations are carried out.

There are 101 of these, most serious of which are probably wind, cup (Fig. 4), or ring shakes (Fig. 5) caused by severe climatic conditions during the tree's growth ; compression and star shakes (Fig. 6), caused by uneven drying or excessive bending at some time ; knots, gum pockets, dote, etc. Some of these defects are permissible, if not too seriously developed, whereas others make the timber quite unserviceable.

The rate of the tree's growth should be carefully noted, the radius of the tree should, under ideal conditions, have increased about 1 in. in six to twenty-one years. The annular rings, of course, make this easily calculable. The grain of the timber is also most important and should not deviate from the straight more than 1 in 15. On some samples the grain is not easily detected, and some inspectors dig out a portion of the wood with a penknife, when the wood tends to split along the grain, showing them its direction, and also giving them an idea of the timber's condition. This method is not to be recommended to the uninitiated, a safer way being to touch the wood with a fountain pen when the ink tends to flow with the grain. Generally speaking, however, the visual selection of timber is definitely an expert's job, and his discretion must be used in deciding to what use the timber can be put. After visual inspection its Izod value must be checked. The nature of the break and behaviour of the fibres are equally important as the load absorbed, which should be about 6 ft.-lb. on a 1 in. square test piece.

Perhaps the determination of the moisture content deserves a little more explanation, as the method employed is similar for air or kiln dried spruce, and plywood. Ideal spruce should have a density of about 25 lb. per cubic foot when moisture content is 15%. To obtain this moisture figure the test piece is first weighed (W1) then cut up into small match sticks, and dried in an oven. At intervals the sticks are removed and weighed, the drying process being continued until two successsive weighings agree (Wo), indicating that no moisture remains in the wood. The percentage of moisture is then easily calculated by a simple formula :—

$$\frac{W1-Wo}{Wo} \times 100$$

If the timber fulfils the aforementioned requirements, it can be said to be suitable for the building of stressed structures, but without the aid of plywood, construction would be almost impossible, and something should therefore be said about this preparation.

Plywood manufacture must be carried out with the greatest care to ensure that it fulfils Air Ministry requirements. It consists, broadly speaking, of three or more thin sections of wood known as veneers, placed on top of one another with the end grain at right angles to the layer underneath, and bound together by a suitable

cement. For stressed purposes, birch is almost invariably used, for though cedar has been tried, it is inferior to birch in every way except from the point of view of lightness.

The veneers are manufactured by rotating the bole of the tree in a large lathe, the veneers being shaved off the trunk as the bole revolves, in thicknesses of from .007 up to 2 mm. for stressed purposes. Birch is particularly suitable for this type of veneer cutting, and panels 9 ft. by 3 ft. are usual, while much larger ones can be cut if necessary. Before the actual manufacture of the ply is begun the moisture content of the veneers is reduced to 6%, for if any quantity of moisture were left in them, the extreme heat which must be used when pressing the veneers together into ply, would tend to produce steam which would be trapped in the inside layers, causing the ply to burst on removal from the press.

In preparation for the pressing of ply, the veneers are laid out on a table one on top of another with an application of cement between each layer. In large sheets of ply it is permissible to join the veneers together, but for convenience in production, the inside layers are, if possible, composed of one piece. Veneer joins on the outside layers are made with tape, which is easily removable after the pressing operation has bound the veneers together. To-day there is also a machine available which will join veneers as thin as .010 in. together, the edges to be joined being passed under heated conical rollers which force them together and effect quite a satisfactory joint. The edges have first, of course, to be glued, but this need not be done immediately before the jointing operation, as a touch of formaldehyde applied automatically by the machine freshens up the glue before the edges pass under the rollers.

Until recently the cement used in the manufacture of ply was always in liquid form, applied with a brush, and finally run over by a "squeegee" roller to ensure that the application was even. Production has lately been speeded up enormously by the use of "Tego" cement, a preparation of Phenol Formaldehyde which has similar properties to the powder used in the manufacture of plastics, liquifying at a temperature of 80°C. and becoming completely hard at 120°C. It is impregnated on to very thin paper and made up in massive rolls, so that the required quantity can be torn off and laid between the veneers just like a sheet of paper.

The veneers are now ready for the binding operation, which is carried out in a steam press, at a temperature of 120°C., and a pressure of 250 lb. per square inch, though this varies with the thickness of veneer used, for a period of about fifteen minutes when "Tego" cement is used. The pressure ensures that the cement penetrates into the veneers, and it is usual to place them in the press between sheets of aluminium which act as heat retarders and

ensure that the cement does not solidify before sufficient pressure has been brought to bear. After pressing the sheet of ply is trimmed up, allowed to cool, and is then ready for inspection, though sometimes the outsides are lightly dusted with a " Sander " Belt to provide a better finish.

Tago cement fulfils most aircraft requirements, as it is unusual to use veneers thicker than 2 mm. the maximum permissible being about 4 mm. Should thicker veneers be needed, Kaurit or blood glue may be used and the pressing operation carried out at a temperature of 90°C and a pressure of 150 lb. per square inch, for the excessive pressures and temperatures used for Tego would damage the fibres of veneers over 2 mm. in thickness.

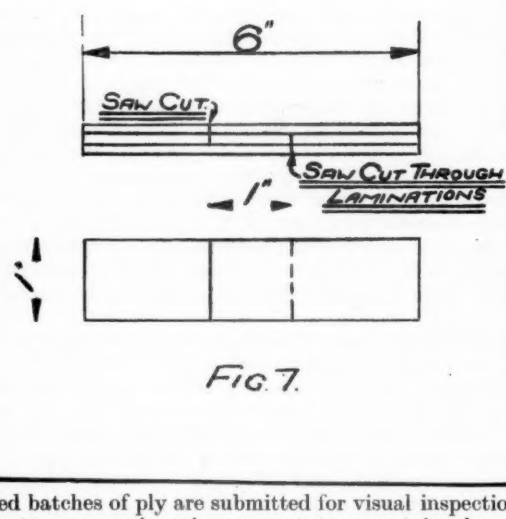

FIG. 7.

Finished batches of ply are submitted for visual inspection, when the inspector may prise pieces apart to ascertain the adhesive quality of the cement. The fibres of the veneers should part before the cement, if the adhesion is correct. Flaws in the gluing can also be detected by passing the sheets in front of a powerful lamp. Tensile tests are also applied to check the adhesive qualities of the cement. Fig 7. illustrates a typical test piece which should absorb a load of not less than 200 lb.

Samples of ply are also immersed in boiling water for three hours, afterwards being allowed to dry. The test pieces are somewhat

larger but must be capable of withstanding a tensile load of 100 lbs. Finally the ply must be capable of withstanding a compression load of 4,500 lb. per square inch.

Suitable timber and plywood have now been selected ready for the building of stressed structures which can be divided into two categories : (a) Fuselage ; (b) Aerofoil or wing structures.

The first fuselage construction carried out in quantities, was accomplished by building a square frame tapering towards one end. Four long ash members, known as longerons, ran down the whole length of the frame, forming the corners of the square and kept in place by other cross bracings of ash in compression. No assembly jig was required for this frame, as adjustable steel wires took the tension loads, and it was possible to true it up by tightening or slackening them the required amount. How good this type of construction was, is illustrated by the fact that modified versions of the old Avro trainer, designed somewhere about 1916, are still in use to-day for joyriding and training purposes, though it has been kept in service probably more for its aerodynamic than structural merits.

It was soon found that by the use of jigs, the sides, roof, and floors could be made up independently and put together in an assembly jig at less expense, and with a saving of weight. The scope for elaborately designed assembly jigs is very limited, but up to the present the small quantities of each type of aircraft produced,

Fig. 8

force the jig and tool designer to make economy his primary consideration.

The sides, roofs, and floors of this type of fuselage usually consist of a framework of wood covered on the outside by ply. Wooden tables or stands conforming to their approximate shapes are first

made, and the framework is then set out on them (Fig. 8). Wooden blocks are then screwed to the table at all the junction points of the framework, setting its position, but not so firmly that it cannot be removed from the table. The outside plywood is next shaped to a template, and glued and bradded to the framework, which can then be removed bodily from the table. Any additional stiffeners such as ply gussets can be added after removal from the table which is now virtually a jig. Any number of units can be made up in this way, it being only necessary to keep the blocks of the jig free from surplus glue and replace them if they become worn.

The assembly of these units into a fuselage is equally simple. The sides usually have the main plane attachment fittings bolted to them and these fittings are used as the suspension points for hanging them in the assembly jig while the floors and roofs are attached (see Fig. 8). Holes have been jig-drilled in the members of the units before their individual assembly so that the accurate location of sides, roofs, and floors in relation to each other is a comparatively simple matter. Fuselages for carrying from two to 20 passengers can be made in this way, and it is a particularly cheap method of manufacture.

Its main disadvantage is that no way has yet been discovered of keeping the ply rigid, and on the larger areas, after the application of a finishing coat of paint, it is most unsightly, giving the impression of a series of waves along the surfaces of the structure.

Several ways of overcoming this have been tried, one, the use of curved members instead of straight ones, the object being to do away with the waves by keeping the outside ply skin permanently in tension.

The finish achieved by this method is not entirely satisfactory and as all the members have to be spindled and the ply bent on special pressing jigs, the improved finish is gained only at a considerably higher cost. Alternatively, the box type of fuselage can have thin spruce members fitted outside the ply, the whole then being covered with fabric. These members are shaped or arranged in such a way that when the fabric covering is fitted, the outside shape of the fuselage is, as nearly as possible, streamlined. Actually this is probably the better method, for though the outside diameter of the fuselage is now from 4 in. to 1 ft. wider that the useful diameter of the cabin, the improvement in shape more than counteracts the extra bulkiness, and, if anything, adds slightly to the speed of a machine arranged in this way. When new, it also has a better appearance, but hard usage, unfortunately, causes this to deteriorate very rapidly unless it is repeatedly re-doped and the cover occasionally renewed.

A more unusual form of construction, usually associated with metal structures, is known as the Monocoque type, which, broadly

speaking, consists of a cylindrical fuselage, tapering towards one end exactly like a cone (Fig. 9). This type of fuselage in its simplest form can be made by mounting four detachable rails in the form of a square on two stands. Circular bulk heads with accurately drilled holes are then slid on to the rails and correctly spaced, spruce stringers joining the bulkheads and holding them in place. The whole is then covered with a ply skin, and to remove the structure from the jib, one stand is disconnected and the rails can then be drawn out.

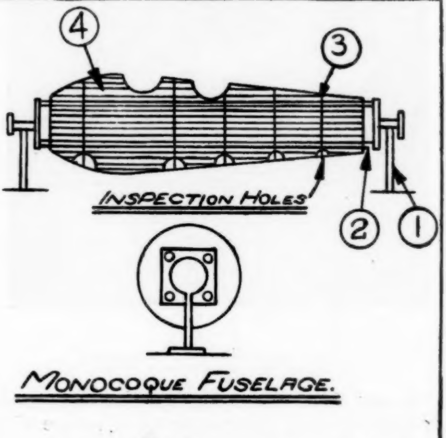

FIG 9.

If greater strength is required, two ply skins may be used, one inside and one outside the stringers. This type is usually made up in two separate halves, on semi-circular jigs made of wooden slats the two halves being subsequently joined together. A stronger method is, however, to substitute two layers of thin spruce slats for the ply and stringers. The layers of slats are laid on the jib diagonally opposed to each other, and bound together by glue and screws. It is possible to achieve more severe longitudinal and lateral bends simultaneously by this method than with ply, but it is rather heavy and therefore usually used on the more severely stressed portions of the structure only (Fig. 10).

The latest method so far used is probably the best and certainly the most interesting. For some years Balsa wood has been used for model making and for improving the streamlining of round sections. This wood grows in swampy land in South America and is extremely soft, porous, and weak, its only virtues being lightness and a

capacity for deadening sound. It is, however, just strong enough to stand planing.

It is well known that the outsides of a member have to resist all the stresses when bending loads are applied to it, and from this fact was evolved what for want of a better name is called the Balsa Wood Sandwich, consisting of one or two thicknesses of Balsa sandwiched between two layers of plywood. The Balsa is used purely

Fig. 10.

for keeping the ply apart and when samples were made they were found to be absolutely rigid, quite as strong as spruce of an equivalent thickness, only two-thirds the weight, and with excellent sound-proofing qualities. The Monocoque shape is particularly suited to this type of construction and fuselages can be produced fairly quickly with a suitable type of jig.

An adequate type of assembly jig is quite cheaply made from angle iron and wood slats (Fig. 11). The top portion consists of several solid sections, but the sides can be retracted inwards. To assemble the fuselage, bulkheads are first fitted in the slots between each section. The whole jig is then covered with a layer of ply which has to be carefully fitted to coincide with the contour of the jig. Layers of Balsa slats are then glued longitudinally to this under-skin and when the desired thickness has been achieved, the outer ply skin is in turn glued to the Balsa. Adjustable pen steel bands are fitted close to one another to act as cramps to each layer, while the glue is drying, and small holes must be drilled in the Balsa wood. in the spaces between them, to allow any surplus glue to squeeze out. The fuselage when completed is removed from the jib by retracting its sides and raising the structure out bodily. Floors and the rear under portion are fitted after its removal. This type of construction

is particularly pleasant from the planning section's point of view, for with the exception of the bulkheads and one or two spruce members, no detail parts have to be supplied to the assembly shops and having provided them with some glue, so many feet of Balsa and so many sheets of ply, they produce a 30-passenger fuselage in about four weeks.

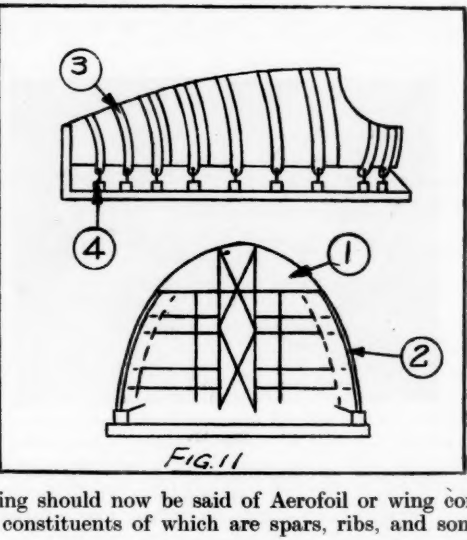

FIG. 11

Something should now be said of Aerofoil or wing construction, the main constituents of which are spars, ribs, and some form of bracing.

Spars can be of the solid, or built up variety, and the choice of these is determined by the size of wing to be manufactured, the solid type being used where possible, as its cost is less. The very best timber must be used for solid spars, and it is usual to spindle out the sides of these, leaving only the top and bottom flanges and places to which fittings will be attached up to size. This spindling effects a saving in weight equal to about one-third of the total spar, which is not weakened in any way, as the top and bottom flanges take the bulk of the stresses, the middle portion acting as a distance piece for them. On production all holes are pig-drilled at this stage, walnut or ash packing blocks are fitted to points where fittings will be attached, and the extremities are treated with bitumous paint to avoid moisture intrusion.

Far larger spars can be made by use of the built up method (Fig. 12). Large spruce members, previously prepared, are spliced together, the length of the splice being roughly 10 times the thickness

of the member, and it has been possible to make spars of over 100 ft. in length by use of this method. The spliced members correspond to the top and bottom flanges of the solid spars, and are distanced by built up packing blocks of spruce or walnut. Sheets of ply are then glued and screwed to each side of the spar and vary in thickness according to the load they will have to absorb at various points on the spar. These spars are assembled on the wooden block type jig, very similar to that used for assembling the fuselage sides.

Fig. 12.

Spars are distanced in wing construction by ribs which are sometimes made up complete and sometimes in sections. The wooden block jig is usually used to assemble them, but a variation of this

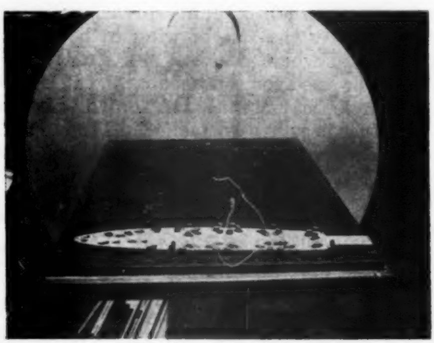

Fig 13.

type is now being used which may be of interest. It consists of a perforated steel table, on which the master template is placed. The main points of this template are located by a number of steel buttons, resembling draughtsmen as used in the game, and not in the D.O. An offset bolt welded to the underneath side of these is pushed through a convenient hole in the table, and the button is then rotated, like a cam, till it binds hard against the locating point on the template. It is held in this position by screwing a nut on to the bolt from the underside of the table. When the pattern is formed, the master template can be removed and rib construction commenced. This type of jig is particularly suitable for the manufacture of small batches, as a set up can be made or broken down in a very short time without actually scrapping any material. The ribs actually supply the contour to the wing and are attached to the spars with metal clips either of pen steel or aluminium, which allow for a small percentage of expansion and contraction without causing any material damage.

Wings are braced in several different ways, sometimes by metal cross struts, interconnected by adjustable steel rods or piano wire. This adjustment is necessary for trueing up purposes as no assembly jig is required. The smaller type of wing is usually made in this way, the covering being effected either by doped Irish linen or plywood. A plywood skin absorbed a fair percentage of the stresses, and a flimsier type of internal construction can be used, or alternatively the metal bracing can be eliminated by the substitution of stronger ribs ; but some sort of jib must then be used for locating the main points of the spar. For a very large wing the ply-covering alone would not be sufficient, but the necessary strength can be obtained by substituting two layers of diagonally opposed spruce slats laid over the ribs and spars in a similar manner to that used for the fuselage construction already described. The wings and parts of the fuselage, of the Comets which flew in the Air Race to Australia were made in this way, and since then a structure of this type has been made capable of lifting a load of 12 tons into the air.

The assembly of various types of fuselage and wing have now been briefly dealt with, but it is felt that something should be said about the prevention of moisture penetration, shrinkage, soundproofing, and attachment methods used in wood construction.

The best moisture preventative for internal structures is bitumastic paint, but it is heavy, slow drying and unsightly and is used only for protecting the extremities of spars, and for portions of fuselages likely to come into contact with water. Oil varnish is most generally used for the protection of the inside portions of structures ; as a protector it is excellent but is slow drying and considerably hampers production, as the drying time for each coat applied is from four to eight hours. Red dope, being constituted

of cellulose and therefore quick drying, has been tried in an effort to eliminate this delay, but it tends to peel off after a time and can only be used in portions of the structure which are already well protected, such as the internal parts of wing structures enclosed by a fabric or ply covering.

The mere application of paint or a cellulose preparation is not considered as a sufficient protection for exposed portions of the structure. It is usual to attach some thin material such as medapolam to the surface first, by means of glue or some adhesive kind of cellulose undercoat. This method provides a far better base for the five to eight coats of paint to be added, as well as slightly increasing the strength of the structure as a whole, without adding appreciably to its weight. Alternatively, the whole structure may be covered with Irish linen which is then treated with five to eight coats of dope, and becomes taut and completely waterproof in the process. If this type of protection is employed the wooden members must be first treated with dope-resisting paint to prevent the linen being stuck permanently to the wood members by it, for should this happen, the necessary outside contour is apt to be distorted, excessive stress may be put on certain portions of the fabric, and the members get torn if the cover is removed to effect repairs.

Sound proofing of structures is receiving more and more attention and in addition to Seapack, an American preparation used by the upholsterer, Cabot quilting, a seaweed preparation sandwiched between paper, was first tried, but is now replaced by Cellocol, made of waste cellulose products.

The soundproofing qualities of Balsa have already been mentioned and if this type of construction becomes popular, it may be possible to dispense with some of these soundproofing devices, effecting a weight saving of about 25 lb. in a cabin with a seating capacity of eight to 10 persons. This may seem very little, unless it is borne in mind that every pound saved in construction means an extra 30 to 40 letters carried per trip on a commercial air line.

Shrinkage and expansion of wood has never been overcome, and can be very serious when machines are flying alternatively through humid and dry atmospheres, when joints and bolts through members tend to work loose. The importance of timber which is properly seasoned in the first place cannot be overstressed, and the extra trouble is well worth while, particularly where large members are attached to one another, otherwise if any appreciable amount of shrinkage develops in one of the members, a crack occurs at the joint, involving the extra expenditure of rectification, if noticed in time, but more often being actually used in this extremely dangerous condition.

Bolts through wooden members can be kept taut by the use of a a special tempered spring steel cup washer, which tends to nullify

any expansion or contraction which may take place. On large wooden built up members such as spars, slots are sometimes cut at right angles to the bolt holes in the centre portion of the member. If the timber tends to shrink, the outside faces are held rigid by the ply packings and the timber therefore contracts at the slots. The bolts remain rigid as the contraction merely makes the gap at the slots larger, and the overall thickness of the member is not decreased in any way.

Various methods of attaching spruce to ply are in use, such as brass or zinc coated screws, screw nails, or brads which must be boiled in resin before use, otherwise vibration tends to make them work loose. These attachment methods are nearly always supplemented by the use of glue or cement. Hot glue is of course the stronger medium, its penetrative powers being far greater. For production purposes, it is not popular because of the necessity for high atmospheric temperature and great speed in the forming of joints with its use. It is used mainly for laminated bends, and packing blocks which are made in a special department, where the atmospheric temperature can be readily controlled. For ordinary workshop use, cold glue, i.e., caseine, cement made from fermented milk treated with sulphuric acid is much more popular. This takes about twenty-four hours to dry properly, does not chill in the ordinary workshop atmosphere, and, provided fresh mixings are made every few hours, has an adhesive power of greater strength than the wood fibres themselves.

It is felt that the foregoing remarks briefly cover the main points of interest to the production mind in the assembly of wooden structures, and from them it would appear that by far the most serious problem to be dealt with is the prevention of shrinkage. Even when the precautions already mentioned are taken, it is still frequently necessary to scrap expensively machined members, or obtain concessions to pack them to the size they originally were before shrinkage took place.

To sum up, then, it seems that wood construction is not yet by any means a thing of the past. The possibilities of the Balsa wood type of construction, have not yet been fully explored and even larger structures than those already in hand may yet be manufactured. Also a great deal of experimental work is being carried out to test the possibilities of impregnating Bakelite into the cells of wood. This is still in its infancy, and one is not in a position to say to what lengths it may be carried, but if the objects are achieved, it will be possible to dry all moisture out of the timber, fill up the cells with some plastic compound, and make it unshrinkable. With spruce an even more important result may be achieved, for it should be possible to double the compressive strength, which is, at present, only equivalent to one quarter of its tensile value, without increasing

its weight to anything like this extent. It is difficult to say to what lengths this may be carried, and it may eventually mean that timber is used simply as a base for some other plastic material.

However for the present, it may be said that for operational purposes in damp humid climates, wood is admittedly inferior to metal, and for military purposes it is discouraged for geographical reasons, yet in many cases the air line operator still purchases wooden structures because for cheapness and ease of maintenance they have no equal.

(*Note.—Mr. Bolton was awarded the Hutchinson Memorial Medal for the best paper by a Graduate,* 1936-37 *session, for this paper*).

PULVERISED FUEL FIRING WITHOUT A PULVERISER.

Paper presented to the Institution, Yorkshire Section, by Commander H. D. Tollemache.

THE subject we are going to discuss this evening is the use of coal in powdered form, or what is usually known as pulverised coal firing. The raw coal is reduced to powdered form by grinding—or, as it is frequently called, pulverising—and, formerly, consumers used to instal pulverising plant at their works to grind their own pulverised coal as and when they required it. We are going to consider particularly certain problems which occur in the pulverisation of coal, the practical difficulties which have been experienced by consumers in grinding their own fuel, and the reasons which have made the elimination of pulverising plant from a consumer's works and, instead, the supply of pulverised fuel in prepared form, a desirable step in the development of this form of firing.

Pulverised Coal Firing Similar to Oil Firing.

Pulverised coal is a fuel, in the same way that oil is a fuel. It is a name that has been given to coal which has been prepared in the form of a fine powder, so that it can be used with equal cleanliness, convenience and flexibility of control to oil fuel. The principles governing the combustion of pulverised coal are, in fact, identical with those for oil firing, but applied to a solid fuel instead of to a liquid fuel. In the same way that an oil burner atomises the oil into a fine spray so that each tiny particle is burned while in suspension, so also with pulverised fuel firing the coal enters the furnace in the form of a fine powder and similarly efficient combustion is obtained.

Composition of Pulverised Coal.

Before dealing with the actual production and application of pulverised coal, I would like to discuss for a few minutes the composition of the fuel itself; as, if a fuel is to be used in the most efficient manner, it is necessary that we should understand its composition and characteristsics. Pulverised coal is composed of a very large number of different sized particles. It has been calculated

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Leeds, January 26, 1937.

that 1 cub. in. of coal when reduced to powdered form so that it will all pass through 100 mesh screen, will comprise something like 50,000,000 particles, ranging from the largest size which just passes through a 100 mesh aperture, down to microscopic sizes. A 100 mesh screen is a sieve having 100 wires and 100 apertures to the linear inch. In the B.S. screen, the wire diameter is 0.004 in. and the aperture size is 0.006 in. When a product is composed of so wide a range of different sized particles, it is essential that we should have some means of classifying and identifying that product, so that its characteristics may be known, and its suitability for different purposes ascertained. Pulverised fuels are classified by ascertaining the proportion of particles which lie on different sizes of screens, and these proportions are then plotted to a curve which is known as the "Fineness Characteristic Curve" for that particular fuel.

Fineness Characteristic Curves.

I wish to emphasise the fundamental importance of these fineness characteristic curves which correspond in pulverised coal, to the viscosities of different oils. In the same way that oils are classified under different viscosities, and we know that lighter oils burn more easily and rapidly than heavier oils, so also pulverised fuel having a "fine" characteristic curve will burn more easily and in a smaller combustion space than a fuel having a "coarse" curve. In the same way, also that a consistent viscosity is most necessary when burning oil fuels—in fact, the oil companies supply oils under rigorous specifications in that respect—so with pulverised fuels a consistent fineness characteristic is absolutely essential if uniform combustion results are to be obtained in the furnace; otherwise unreliable and varying results are bound to occur.

Combustion Process.

I would now like to discuss the combustion process which takes place with pulverised fuel firing. One pound of coal requires 126 cub. ft. of air for complete combustion, or something like 8,000 times its own volume. You will appreciate that the only part of a lump of coal which is available for the oxygen of the air to get to is its external surface; and if we take a lump of coal of 1 cub. in. in size it has a surface area of 6 sq. in. available for the oxygen to get to. One of the results of reducing coal to powdered form is that the surface area of the fuel is very largely increased; and, if the cubic inch of coal is reduced to a powder so that it will all pass through a 100 mesh seive it has been estimated that the combined surface area of all the tiny particles added together would then amount to about 2,000 sq. in., or some 300 times as great as the original lump. It will, therefore, be appreciated that the reduction of coal to powdered form very greatly increases the ease with which the oxygen of the air can

get to the fuel to enable combustion to take place ; and it is for this reason that combustion efficiencies comparable to oil firing are obtained.

As to the actual process of combustion which takes place when a coal particle is burning while in suspension, the first stage is that in which a coal particle in which combustion has started surrounded by a layer of oxygen. In the first place the volatiles from the coal are given off and the coal itself gradually becomes a semi-coke. With bituminous coal, the volatiles within the particle frequently cause it to swell in the form of a bubble, known as a "Cenosphere," which again increases the surface area available to oxygen. As combustion continues, the semi-coke becomes a coke and the Cenosphere again usually breaks up into further small fragments of coke. In the final stage the small particle of coke continues to burn until all combustible matter has been consumed.

It has been estimated that a particle of 200 mesh in size takes about one-fifth of a second to complete these four stages ; whereas a particle of 60 mesh size takes about two seconds, or ten times as long. From this will be seen the great importance of maintaining the fineness characteristic curve of the fuel consistently within the limits of fineness which enable all particles to be consumed while in suspension, and to ensure that no particles shall be of too large a size for this to be effected.

If a particle is too large to enable combusion to be completed while in suspension it will either fall out of the flame zone and be unconsumed, causing carbon-in-ash losses or, which is even worse, it will be carried by the gases out of the chimney and cause grit nuisance and troubles in the surrounding neighbourhood. Nearly all the complaints which have, in the past, caused a certain unpopularity for pulverised fuel, have been due to inefficient and inconsistent grinding and, therefore, incomplete combustion of the fuel in the furnace.

Rittinger's Law.

It may be asked why, if the finer the characteristic curve of the fuel the more easily it burns, pulverised fuel of the finest possible characteristic is not always used. The reason is that, although the finer the powder the greater is the surface area exposed to oxygen, the cost of production also increases, the finer the fuel is ground. Dr. H. Heywood has shown that the power required to produce a certain degree of fineness is very closely proportional to the corresponding increase of the exposed surface of the particles. Taking a sample which has an average fineness of 100 mesh, the superficial area of 1 lb. is 200 sq. ft., and the power required to produce that fineness is 5 h.p. hours per ton. If we take a sample having an average fineness of 200 mesh, the superficial area will be

450 sq. ft., and the power required becomes 11.25 h.p. hours per ton. I would like to point out that the power scale represents the actual power required to break down the coal, and does not take into account the milling efficiency of the machine. If the mill has a milling efficiency of, say, 25% (by which is meant that out of 100 units of work put into the mill, 25 are used for the actual breaking of the coal), then the power required to produce the sample of 100 mesh size will be 20 h.p. hours per ton; while that required for 200 mesh will be 45 h.p. hours per ton.

It will, therefore, be seen that while pulverised fuel must be of sufficient fineness to ensure that all the particles are burned while in suspension, it must not be ground to an unnecessary fineness, or the cost of production will largely discount the economies obtained.

Production of Pulverised Coal : Types of Pulverisers.

I would now like to deal briefly with the practical production of pulverised fuel, and describe the three principal types of pulverising mills in use to-day. They may be divided into the following groups :

Group 1 : Slow speed type—for example, ball mills.
Group 2 . Medium speed type—for example, ring roll mills.
Group 3 : High speed type, or inpact machines.

I would like to emphasise at the start, however, that all these types must conform in their performance to the power/fineness laws I mentioned previously.

Group 1.—The slow speed or ball mill type is, perhaps, the best known and most reliable of the three. It consists simply of a drum carrying a charge of steel balls, and, as the drum rotates the ball charge cascades over and over and grinds the coal. The coal is fed in through one of the trunnions and the mill is air swept, the current of air passing through from one trunnion to the other which carries the pulverised coal out air-borne, as soon as it is ground. On leaving the mill, the coal dust passes through the classifier. All mills are fitted with classifiers which prevent, as far as possible, very coarse particles from passing in to the pulverised coal system. These particles are rejected and passed back to the mill for further grinding. Classifiers, however, only possess a certain efficiency and I shall explain later how, to maintain a constant fineness, adjustments to the mill feed have to be made.

Group 2.—The second group is the medium speed or ring roll type. This consists of rollers revolving inside a ring, the coal being ground between the rollers and the ring. This type is again air swept, the air current removing the pulverised coal from the grinding zone as it is ground. There are many variations of this type of mill in use, in some of which the ring revolves, and in others the rollers revolve ; but they are all similar in principle.

GROUP 3.—Finally, we have the third group, which is the high speed or impact type, and which consist of a disc having a large number of pegs or " beaters " on it, revolving at a very high speed, the coal passing through the pegs on the revolving disc and others on a stationary disc. The mill is again air-swept, a current of air passing through the machine and drawing the pulverised coal out through a classifier as it is ground. As before, there are many different makes of impact machines in existence which differ in minor points of design or detail; but they are all similar in principle and conform to the same grinding laws.

Variations in Performance of Pulverisers.

The performance and efficiency of pulverising mills, of whatever type, are affected by certain internal and external factors which unless watched for, will cause variations in fineness. A mill which is producing a certain output of pulverised fuel to a specified fineness, will continue to maintain that fineness so long only as the conditions remain unaltered. I would here like to explain the balance which always obtains in any type of mill between output and fineness. If a particular mill produces, say, one ton of fuel per hour ground to a certain fineness, it means that that quantity of powder represents a certain expenditure of power by the machine. If, for any reason, the efficiency of that machine falls off and we continue to feed one ton of coal per hour into it, then owing to the reduced efficiency of the machine, less power is available to do the work of grinding and, consequently, the fuel will not be ground so fine. That is a mechanical law which no machine, of whatever make, can escape from; but as, in practice, it is, of course, the fineness which is all important and which must be kept up to the required standard, the falling off in efficiency of the machine is compensated for by reducing the mill feed, so that owing to its lower efficiency the mill will produce only, say 18 cwts. of pulverised coal per hour to the requisite fineness, instead of one ton. There are several factors which tend to affect the efficiency of pulverising machines, and which will cause a deterioration of fineness unless compensated for by reducing the mill feed.

In the first place, the quality and characteristics of the coal to be ground has, as would be expected, a marked effect on the performance of the pulveriser. Coal is not a homogeneous substance, and its characteristics vary widely not only in different parts of the country, but even in the same seam. Coal is now being classified by a factor which is termed its " grindability factor," which is a measure of an intrinsic characteristic of the coal, expressing its resistance to grinding. A mill which is grinding coal from, for instance, the Welsh 9 ft. seam, will have a greater output to a specified fineness than an identical mill grinding South Yorkshire

coal. Thus the mill feed must be carefully regulated depending on the grindability of the raw coal used, in order to maintain a constant fineness of product.

To maintain the product to a specified fineness, the mill feed must be correspondingly reduced to compensate for the effect of an increasing atmospheric humidity. The mill feed must be reduced if the surface moisture of the raw coal increases, in order to maintain a consistent fineness of product. In Group 1 the effect of wear more quickly reduces the grinding efficiency than in Group 2. In both types of machine the mill feed must be gradually reduced as wear of parts takes place if consistent fineness of product is to be maintained. After the worn parts have been renewed, then the mill can once more operate at its full output until wear starts once more to have effect. In the case of ball mills, wear of parts does not affect mill performance in this manner, since the grinding media is maintained at a constant weight by the addition of extra balls while the mill is in operation. I have dealt at some length with these grinding problems, which are present with all types of mills, in order to emphasise that the reduction of coal to a uniform and consistent powder is by no means a simple matter, but a process requiring highly specialised supervision and attention.

Pulverised Coal Systems.

Having described the composition and combustion of coal particles, I would now like to go on to the application of pulverised coal in practice. The two systems which have been developed for the application of pulverised fuel with the use of local grinding plant are generally known as : (1) The direct-fired or " unit " system ; (2) the bin and feeder or " central " system.

In the direct fired system, coal is fed from the raw coal hopper direct into the mill, where it is ground to pulverised form. This mill may be of any air-swept design, either of the impact, ring roll, or ball mill type. The sweeping air is drawn through the mill by a fan, which may be either combined with the mill itself, or independent. The pulverised coal withdrawn from the mill by the air current then passes direct into the furnace with the requisite additional secondary air to complete combustion. The fuel feed to the furnace is thus regulated by the coal feed to the mill.

There are certain considerations in connection with the unit system of firing to which I would now like to refer, as they have led to the development of the central system.

In metallurgical work, control of furnace *atmosphere* is of equal importance to control of furnace temperature. In copper refining, for instance, it is known that the mechanical properties of the copper are directly affected by the oxygen content of the furnace ; and the same applies in a greater or less degree in almost all melting,

re-heating, or annealing work. Accurate control of furnace atmosphere is one of the great advantages to be derived from oil or gas firing for metallurgical work, and consumers have been willing to pay more for their fuel in order to be assured of this advantage. With pulverised fuel equally accurate control is obtainable, provided that the firing equipment enables the fuel feed and combustion air to be regulated with the same precision as with oil or gas, and that no uncontrolled variables which can affect furnace conditions are allowed to intrude.

If washed fuel is used with the direct-fired system, the moisture in the coal is evaporated during the process of grinding by passing hot air through the mill for air sweeping. The moisture thus removed, however, passes *into the furnace with the fuel*, thus at once introducing a varying and unknown element which materially affects furnace conditions. Further, the temperature and volume of the hot gases used for drying, will be dependent on the initial moisture of the raw coal; whereas the volume of gases required for the duty of air sweeping are dependent on the fuel feed and fineness required. With the direct-fired system, therefore, there are three duties for the air combined into one, i.e., the drying of the fuel, the sweeping of the mill, and the conveyance of the fuel to the furnace. In practice, the actual air quantities for these three functions may be and usually are entirely different; but, when the same air has to carry out all three duties, an alteration to obtain the most efficient results for one cannot be made without affecting the others also. Accurate control of furnace conditions and atmosphere with the direct fired system has, in consequence, frequently been found a matter of great difficulty, and this has led to the development of the bin and feeder system.

In this sytem each stage in the process is carried out separately. The raw coal is first dried in an independent dryer, the moisture laden gases passing away to atmosphere. The temperature and volume of the drying gases can thus be regulated to the exact requirements for the evaporation of the moisture, depending only on the moisture content of the raw coal.

The *dried* coal then passes to the pulveriser, through which the sweeping air passes, removing the powdered fuel and depositing it into a cyclone collector or bin; the return air from the cyclone leading back again to the mill. The sweeping air circuit is, therefore, again entirely independent of the rest of the system, and can be regulated to the exact degree required for the mill output and fineness desired.

Finally, the pulverised fuel itself is fed by a regulatable feeder into the primary air circuit, so that the fuel feed and air entering the furnace are again adjustable to the exact quantities required, entirely independently to the drying and pulverising processes.

By this system, therefore, an accurate control of furnace temperature and atmosphere is obtainable, since the fuel and air feed is entirely independent from fluctuating variations incurred in drying and pulverising.

Disadvantages of the Unit System.

When we remember the various factors which affect the performance of pulverisers, it will be noted that in the case of the central system the mill feed can be adjusted as required to compensate for these variations, so that the fineness of the product deposited into the bin can always be correctly maintained. In the case of the direct-fired system, however, the mill feed also governs the fuel feed to the furnace and cannot in consequence be altered to maintain a consistent fineness without altering the fuel feed to the furnace also.

With the direct-fired system, therefore, the maintenance of a consistent fineness has to give way to the necessities of the fuel feed to the furnace and, in consequence, less efficient results and more variable conditions are inevitable, than with the bin and feeder system.

Supply of Pulverised Fuel in Prepared Form.

The production and marketing of pulverised fuel in prepared form, really corresponds to removing the whole of the drying and pulverising plant from the consumer to the fuel supplier, so that the consumer is left only with the bin to receive his fuel and the simple feeder to supply the burner. The production and marketing of pulverised fuel in prepared form, therefore, transfers all the problems of fuel production to which I have referred from the consumer to the producer of the fuel; so that the consumer can then look for the supply of a fuel of consistent specification without further worry. The whole of the coal preparation side of the installation becomes the responsibility of the fuel supplier, and the elimination of this equipment from the consumer's installation removes also the bulk of the capital and operating costs for the use of pulverised fuel, compared with those installations where grinding plant is installed.

Additional Advantages of Elimination of Local Pulverising Plant.

As would be expected, the comparative capital outlay for pulverised fuel plants with and without pulverising plant, shows a saving of frequently as much as 75% of the capital cost when a plant is installed without pulverising machinery. Operating costs are similarly far lower, both for power and maintenance.

As with other commodities, a high load factor is essential for the economic production of pulverised fuel, when all charges contributing

towards preparation costs per ton become correspondingly reduced. The cost of production falls rapidly as the output from a given plant increases, and few ordinary sized works have so large a fuel consumption as to be able to operate a local pulverising plant at an economic output.

When pulverising plants are fitted as units to individual furnaces they represent capital lying idle, while still liable to capital and depreciation charges, whenever the furnace is not in operation; and it will thus, in most cases, be possible to supply individual works with pulverised fuel in bulk from a central plant, at a lower cost than they could prepare it for themselves on site. This has already been appreciated in Germany and America, where unit machines already installed have in many cases been discarded in favour of receiving supplies of pulverised fuel in prepared form.

Last, but by no means least, is the question of safety. It is common knowledge that in the past fires, and even explosions, have occured in pulverised coal plants; but these have always been in connection with the coal preparation plant for drying and grinding the coal into pulverised form. It is in the grinding section of the plant that the risk, if any lies, and where very careful supervision of temperatures has to be kept to ensure that there is no danger of spontaneous combustion while the pulverised coal is being made. The supply of pulverised fuel in prepared form eliminates the grinding plant from the consumer's works and, therefore, makes the use of pulverised coal absolutely safe, so that all the danger and risk is removed.

It was with the object of making pulverised fuel available to consumers in prepared form that the first plant in this country was erected about three years ago in Yorkshire.

The Production and Marketing of Pulverised Coal in Bulk.

The grinding mills used in this plant are of the ball mill type. After the fuel is prepared—and it is tested in every stage of its preparation to ensure absolute accuracy in specification—it is loaded into specially designed road or railway tank vehicles, in which it is transported to the consumer's works. A rail tanker, having arrived at a works, discharges the fuel into the consumer's bunker. The fuel is discharged pneumatically through a pipe direct into the bunker with equal cleanliness and convenience to oil fuel, in twenty minutes to half-an-hour.

Transport by road is effected in specially designed road tank vehicles, The vehicles carry about five tons of fuel each. In order to empty the tanker complete it is arranged to tilt.

Savings Obtained with Pulverised Fuel Firing.

As to the savings which have been obtained from the use of pulverised fuel, with the same furnaces previously operating on

hand firing, it is the case that given similar convenience and flexibility of control, the value of a fuel from the consumer's point of view, lies in the quantity of heat which it can economically be made to yield, and the price which has to be paid for that heat. In this connection pulverised fuel compares favourably with all other fuels giving similar convenience, such as gas, oil, and electricity.

Concluding Remarks.

In conclusion, I think that with this method of supply, pulverised fuel can now be regarded as one of the standard industrial fuels, giving similar advantages of cleanliness, convenience, and flexibility of control to oil or gas ; but, at considerably lower price per heat unit. Apart from the benefit of the cheap price of heat, this development in the use of pulverised fuel will also help our natural fuel—coal—to compete with imported oil ; and in that way also assist the coal industry not only to retain but to retrieve markets which have previously been lost to oil fuel.

Discussion.

MR. R. J. MITCHELL (who presided): The principal thing I have learned from Commander Tollemache is that the old idea, which I feel sure is somewhat current, that any old trash in the carbonisation of fuel was good enough for pulverising, has not been quite a correct idea. It seems that the same old law that applies in most regions of practical work, namely that the more you pay for a product made in a competitive market, the more you get for your money, largely obtains in this field. Nevertheless, in my mind there is still a doubt. This remarkable technique of fuel preparation seems, by implications from Commander Tollemache's remarks, to be unavailable for low grade fuels, and I would like him to amplify his remarks concerning this phase of the subject. It would be heartening to think that the millions of tons of fuel of quite low commercial value in years gone past may perhaps have a utility when pulverised for such jobs as firing in specially constructed grates such as are employed in large steam generators in power stations.

My other question concerns the physics or chemistry or both, of combustion itself by powdered fuel. If one listens to modern combustion engineers, one will hear a lot of talk of long flame versus short flame, damage to furnace walls by oxidising flames of wrongly controlled burners. One wonders what is the relation between desirable fineness of pulverisation from a flotation standpoint and rate of combustion in terms of flame density, which really mean flame length. That seems a very important question in modern power plants involving fireboxes of enormous capacity.

COMMANDER TOLLEMACHE: The two points you raise, Mr. Mitchell, are very interesting ones. On the question of utilisation of low grade fuels there is no doubt that by reducing coal to powder form you do facilitate its combustion, and improve its combustible properties. When we are considering fuel from the commercial standpoint, the amount of heat contained in that fuel is really the fact which the works manager wishes to ascertain. The less the ash, the less the moisture, and the less the incombustible matter in the fuel—the more heat is he going to get for what he pays. He is going to pay the same for transporting ash over the railways as he is for fuel; and, therefore, from the commercial point of view there is no doubt that the higher the grade of the fuel and the higher its calorific value, the greater is its value on a heat basis. The chairman has, however, quite rightly pointed out that there is a good deal of low grade fuel produced at collieries, and the question is whether or not that low grade fuel can be made use of in some way. Although

not quite within the scope of the subject we have been discussing to-night, which is the marketing of fuel in prepared form, this low grade fuel can be used in pulverised form, with advantage, at the colliery itself. The modern tendency at collieries is to dedust coal before washing. In so doing the washing process is increased in efficiency, the washer water is kept clear, and the selectivity of the washery is improved. The washed products are the better for removing the dust from the slack before washing, and that dust can be very profitably used in pulverised form at the colliery pit head. There is no question here of transport, as it is available on the site where it is produced. Low grade fuel of 18% ash can be efficiently used in pulverised form for steam raising purposes on the colliery boiler plant, and so release for the market any saleable coal previously used for that purpose. I may mention the case of a boiler plant at a colliery in Yorkshire which is running on pulverised fuel obtained from the dust extracted from the coal before washing. It is of interest as being the largest Lancashire boiler plant using pulverised coal in the world. This boiler plant has now been running for upwards of three years utilising a low grade fuel of 15 to 18% ash.

Now, as to the relation between fineness and flame length. The larger the particle, the greater is the particle combustion time, and, consequently, the greater the flame length required for that particle to be consumed. In boiler plants of the Lancashire boiler type a fairly long flame is desirable because the radiant properties of a pulverised coal flame are actually higher than those of other commercial fuels, such as oil or gas. A flame stretching along the flue of a Lancashire boiler enables the heat transference to take place along the whole length of the flue, instead of only just at the end where the firegrate is.

For metallurgical work, in nearly all cases, the flame requires to be shorter than for steam raising purposes, and for that reason a consistent fineness characteristic is of the utmost importance. Coarse particles in metallurgical work may fall on the product and cause considerable damage, and it is, therefore, of vital importance that the particles must be all of sufficient fineness to be burnt whilst in suspension.

MR. A. SYKES: It struck me on listening to the lecture that there must be some limit as to the size of plant you are working whether it pays you to pulverise your own fuel or it pays you to buy it. Obviously, if you are a very large user it will be best to buy your own pulverising machinery rather than buy pulverised fuel. What quantity per week becomes a paying proposition to buy it pulverised rather than make your own? Commander Tollemache speaks of certain sizes of screens. Is it the number of wires per inch, or the size of holes forming the screen.? Another

question is that of applying pulverised fuel to works' heating apparatus of a comparatively small size, as distinct from steam raising apparatus ; is there any experience available on installations of this kind ?

COMMANDER TOLLEMACHE : Like all other commodities, a good load factor is essential for the economic production of pulverised coal. The greater the output from the given plant, the lower will be the actual cost of production. Few ordinary size works have sufficient coal consumption to make it economical for them to grind their own fuel. The machines which supply individual furnaces represent capital lying idle, still liable to depreciation charges when furnaces are down for repairs. I myself would say that for a coal consumption exceeding 200 tons per week it might be more economical to prepare the fuel locally, providing the works were willing to pay the high capital cost required for the plant, were prepared to make a close study of the subject and provide and train a special staff to supervise the preparation of the fuel. In Germany, where I went to study the supply of powder fuel in prepared form, which has developed to a greater extent there than it has here at present, I saw quite large coal pulverising plants lying idle in favour of receiving the fuel in prepared form. The works engineers told me that although the plant has been installed at considerable expense and capital outlay, they now purchased the pulverised fuel in prepared form in preference to making their own, with all the supervision and trouble it involved if a consistent high grade fuel were to be produced.

Size of sieve. I am sorry I did not make that quite clear. A 100 mesh sieve is a sieve which has 100 wires to the inch. There are various standards, but the British Standard sieve is now used in this country. In the 100 mesh British Standard sieve the aperture is 0.006 in. and the wire is 0.004 in. diameter.

Small heating apparatus. We have not yet developed this commercially in this country, although we are now experimenting in that direction. In America they have small central heating plants operated by pulverised fuel, and I have seen pictures of several installations of that nature in houses ; but we have not yet quite reached that stage in England yet.

MR. F. T. NURRISH : It appears to me there is one point where Commander Tollemache has been rather unfair in discussing the economics of the various fuels. Electricity was dealt with economically in a very unfavourable manner. I think it would have been much more to the point if Commander Tollemache had pointed out that electricity, under certain circumstances, could be competitive with the other fuels even at the price of ½d. per unit, when it is taken into consideration the economy that can be effected by properly lagging furnaces, and also due to the fact that there are

no waste products of combustion, and in a properly designed appliance all the input can be used with very little loss. No doubt a number of persons in this room have had experience of electrically heated furnaces and appliances which compare economically very favourably with similar kinds of plant employing other fuels. In addition there is the factor of saving of labour due to the possibility of fitting automatic controlling devices to electrically heated furnaces and other apparatus, and also the advantages of cleanliness to take into account when considering the use of electricity as compared with other fuels.

COMMANDER TOLLEMACHE : The figures can be quite easily calculated. One kilowatt hour is equivalent to 3,412 B.Th.U's and, at a price of ½d. per unit for electricity, is equal to 14.7d. per therm (100,00 B.ThU's). Mr. Nurrish is quite right in saying that electricity has advantages in certain cases from the point of view of cleanliness and simplicity ; but on an actual heat basis electricity is by far the most expensive form of fuel, whereas pulverised fuel is the cheapest. The reason is that, in the preparation and distribution of pulverised fuel there is no thermal loss, the calorific value of the fuel as fired being equal to that of the raw coal from which it is made ; whereas in the production and distribution of electricity certain losses are inevitable, which result in a correspondingly higher cost per heat unit to the consumer.

MR. J. WILKINSON : There are one or two points upon which I would like to have information. Firstly, is the pulverised fuel simply supplied in one grade, or can it be purchased in various grades of fineness, and secondly, in various grades with regard to composition ? Will you guarantee your sulphur and ash contents within reasonably narrow limits ? What is considered a reasonable loss of efficiency before the plant should be put off for repairs, and approximately what length of time would it run before being put off for repairs ? Can Commander Tollemache give us any information concerning the use of pulversied fuel with internal combustion engines ?

COMMANDER TOLLEMACHE : The fineness I mentioned of 95 to 98% through 100 mesh gives particle combustion times which are satisfactory for most commercial applications. It will be appreciated that to go finer adds to the cost of production. Small furnaces previously fired by oil are now being successfully fired by pulverised coal marketed in prepared form and supplied to fineness of 95% through 100 mesh. Pulverised coal is supplied in both finer and coarser grades, but in these cases it is usually used for other purposes than fuel, e.g., foundry dust, etc.

Sulphur and Ash. One of the advantages of passing the responsibility of the specification for the fuel to the fuel suppliers is that the latter can take the study of the analysis of the fuel, etc., off

the shoulders of the consumer. In the preparation of pulverised fuel for the market, each truck of raw coal that is sent to the plant is analysed before receipt and has to lie within certain specifications for ash, etc. On the matter of sulphur, I think that is again an advantage in putting the responsibility for analysis on the supplier of the fuel, then he is in a position to select raw coal from a seam which has a low sulphur content. It is difficult for the ordinary consumer to select the seam from which he actually obtains his coal, and be certain of getting it.

The curves referred to were shown by the courtesy of Mr. Farrant, they were really comparative curves. The effect of wear varies very greatly on the grindability of the coal used, and for that reason it is not possible to say actually as to the length of time any particular machine will last without replacements, but the effect of wear will probably start to be noticeable with high speed machines after one month, and after three to four months with medium speed pulverisers.

I do not think up to the present any great advances have been made in connection with pulverised fuel for internal combustion engines. As I expect you know, in Germany the Rupra motor has been tried out on pulverised coal now for some time while the original Diesel engines were run on pulverised coal and not oil. I do not think the pulverised fuel internal combustion engine has yet reached a commercial stage, and I gather the problem is more metallurgical than one of combustion.

Mr. Mitchell: Reference was made to a serious falling off in grinding efficiency with increase in air humidity. I would like if possible some illustration on that point. Did I correctly interpret the point to be that even though the air may be at a temperature above its dew-point—well above its dew-point—that its absolute content of water existing in gaseous form determines a falling off in grinding efficiency with increase of total moisture?

Commander Tollemache: The reference was to the effect of atmospheric humidity, at normal atmospheric temperatures, on the grinding efficiency of machines.

Mr. A. Sykes: Could Commander Tollemache give a rough idea in the case of a billet heating furnace, what percentage of the total heat in the fuel is actually transferred to the billet in useful form and how much goes up the flue?

Commander Tollemache: That is a very interesting but a difficult question to answer, owing to the difficulty of obtaining the efficiency of metallurgical furnaces—by which is meant the amount of heat put in with the fuel in relation to amount of heat actually given to the product. In a boiler we can measure the amount of heat which is transferred into the water by measuring its volume and temperature, but it is a very difficult matter to measure the amount of heat which is actually transfered to the product of a

metallurgical furnace. From the operating point of view one can form a comparison by noting that as whereas underhand firing you may be using say 10 tons of fuel per unit weight of metal treated, with the use of pulverised fuel you may require only 5 tons of fuel for the same weight of product. This means that whatever the efficiency was before, there has been a marked improvement, but, exactly what the actual furnace thermal efficiency is would be difficult to obtain in practice.

TIME AND MOTION STUDY.

Paper presented to the Institution, Yorkshire Section, by G. M. Hall.

Introduction.

THE subject of time and motion study, particularly time study, is undoubtedly one of the most controversial in present-day industry, probably as it is so often coupled in discussion with systems of payment by results, which is only too frequently the cause of its being misunderstood.

In time study we are interested only in one of the factors which enter any system of payment by results. It is well known that any system of payment by results may be expressed by the formula time × rate = contract wage. Of the two factors time and rate, only one is capable of measurement—time—rate being fixed by either economic conditions local or national, or by barter between employer and employee. With this in mind this paper is limited to the factor which is capable of measurement, time, and does not deal with any form of incentive or system of payment by results. In dealing with time and motion study we have two entirely different studies each requiring entirely different methods of analysis and application. Though their methods are widely different, the two are closely interconnected.

On studying the manufacture of any article it is found that the whole process is built up in the following manner :—

(1) *Elemental motion*—the smallest measurable part of any action involved.

(2) *Operation*—the stage in the manufacture comprising a complete cycle of motions.

(3) *Process*—a series of operations performed by one or a group of workers.

(4) *The complete job*—all the processes necessary in the complete manufacture.

The motion study analyst is interested in the elemental motion and the operation from the viewpoint of the best way, and the time study observer in the right time. The motion study analyst is also interested in the connection of the processes, and the time study observer in the process itself.

It can be seen, then, that the two are inseparable. It would appear quite futile to make an elaborate time study of a particular job, if in that job there are a multitude of waste motions. In the

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reverse case it is equally true. There is little use in analysing a piece of work and obtaining the minimum number of motions and a minimum of fatigue necessary to perform that work, unless correct time study is afterwards applied to measure the right time for performing that cycle of motions. Since the two methods are quite different they are dealt with quite separately under their own headings.

Time Study—Its Object.

When any subject is under discussion the first question to be answered is "What is the subject?" Then, "What is Time Study?"

Previously it has been shown that any manufacturing can be broken down to the primary elements of motion, that the only common basis for the variety of operations is time, and that it is with the time necessary for these elements to be performed that time study is concerned.

The best answer to the question then would appear to be: "That time study is the breaking down to its fundamental elements of all work, having due regard to the fatigue incurred, the object in view being to allow the right amount of time for a given amount of work to be performed."

This is, in itself, the primary purpose of time study, to ensure that there shall always be the same amount of work done in a certain time. To-day, however, with industry becoming more and more complex, time study assumes a number of other important aspects.

With competition increasingly active and high overheads, time study provides the one firm basis for preparing estimates before the work is done, and for applying overheads on completion so that profits may be realised.

It can also be used for measuring the efficiency of a works with a view to maintaining or increasing a level of performance with its ultimate effect on cost, and is a valuable guide in the preparation of delivery schedules. In fact, it has been said that time study is by far the most important element of scientific management.

To sum up the objects of time study, it is found that they are: (i) Primarily to ensure the right time for the work to be done; (ii) as a basis for estimating and costing; (iii) as a guide to management.

The history of time study is comparatively recent, dating from about 1880, its pioneer being Frederick W. Taylor, an American. Taylor it was who realised, whilst engaged in industrial research, that any task could be broken down into elements, and that fatigue might and did vary on each of these elements. He also realised that if these elements were always recorded in the same form they could be compared or averaged, and standard times for recurring elements produced. In spite of opposition he proceeded with his ideas and laid down the fundamental principles which form the

basis of the methods used to-day. Since Taylor's time, time study has progressed rapidly, but its applications in this country are fairly recent.

Type of Operator.

Before making the actual study, a difficult problem must be decided. What type of operator should be studied? Should the best operator be studied? Should an endeavour be made to find the average operator, a most difficult problem, or should the study be made on the operator who happens to be doing the job? Taylor always studied the best operator, but frequently the answer to the question is decided by conditions, particularly in mass production, where it is a case of one operator, one job. It is perhaps best, then, if possible, to study a number of operators on the same task, in an endeavour to reach the average.

Another question also arises—how long should an operator be on a particular task before he is studied? This also is most difficult to answer, with the varying degree of skill which is obtained by operators. If the operation is one which is being, or will be, performed continuously, then a period of a fortnight to three weeks should be sufficient before taking observations on that particular operator.

The problem is even more difficult where the operator is skilled at one class of work but has many different jobs in that class, an example being an operator of a sensitive drill, who has many different jigs to deal with. The operator is an expert at his own class of work, but in the change-over from one jig to another there is a definite loss of dexterity with each change, even though the same jig may be used within a few days. It would be reasonable in cases of this nature to allow the operator three runs on a new job, to become accustomed to handling the jig and work, and to take studies over the next run at different times to endeavour to fix the skill factor.

Methods and Equipment.

The methods and equipment of the time study observer are quite simple. First comes the stop-watch, which is usually of the seconds or decimal hour type, having preferably independent stopping and resetting mechanism.

Secondly, the analysis sheet. This and the watch are usually attached to an observation board, so that the watch is under the control of the left hand.

The observation sheet is usually divided horizontally and vertically, the vertical divisions representing the elements and the horizontal divisions the cycles. There are of course many variations in design of the analysis sheet to suit various individual requirements.

Making the Study.

When making a study, the observer usually studies the job closely for a few cycles until he is able to split it into its different elements, these elements then being written in the headings of the vertical columns. This having been done the watch is started, either at the commencement of a cycle or at the beginning of an element, being sometimes easier to locate on a particular element than on the commencement of a cycle. Once the watch is started it should be allowed to run continuously.

The observer notes the readings of the watch as the elements occur and enters them horizontally across the sheet in the columns provided. Should any element foreign to the job occur, such as the dropping of a tool, the time and start of this foreign element are recorded in a special space provided with alphabetical codes. The code letter is then entered in the element column where the foreign element has occurred.

The observer continues his study until he is satisfied that he has obtained all the information he requires. The time of taking the study is then noted on the sheet, and conditions prevailing, these being important from the point of view of fatigue. This completes the actual making of the study.

Analysis.

Next the foreign elements are removed from the actual elements. These are then studied closely. If any times are very high compared with the general times for the elements concerned they are ringed round and investigated. If no reason is found for being high they are ignored. Likewise if low readings are found these are also investigated, as, if there is no error on the part of the observer this represents the time in which the element can be performed. When this check is completed the columns are totalled and divided by the number of elements which have been taken into the study, to find the average, against which is also shown the highest and lowest time to show the degree of variation.

Next, and what is probably the most difficult part of time study, comes the rating of the elements. This is done by means of levelling factors, applied either individually to each element, or as a collective factor across the whole cycle, in which case it is known as blanket rating. These levelling factors are arbitrary figures built up on experience of the particular type of work under observation, and are applied on the basis of : (i) Skill ; (ii) effort ; (iii) consistency ; (iv) conditions.

The object of these factors is to set time values for the work which can be expected of the average person under normal circumstances.

A specimen set of levelling factors is shown below :—

Skill		Effort	
Super	1.3	Killing	1.3
Excellent	1.2	Excellent	1.2
Good	1.1	Good	1.1
Average	1.0	Average	1.0
Fair	0.9	Fair...	0.9
Poor...	0.8	Poor...	0.8

For the average in every grading then the factor is 1, so that if an operator is stated at average in every grading, the basic time allowed will be the time shown. The factors step up for high rating, say, for instance 1.1, 1.2, and down for low rating, and the element time is multiplied by the factor.

For example, say we have an element time of ten seconds and the observer has decided on a rating of high effort 1.3, then it is obvious that the average operator will require more than ten seconds to perform this element, so if the 10 seconds is multiplied by the rating 1.3 we find that the average man requires thirteen seconds. On the other hand, had the rating been poor, say 0,7. then the time allowed would be seven seconds.

The rating factor having been applied to each element we have the basic time necessary for each element.

The total time to be allowed for performance of the work is built up of :—

(1) *Basic Time*—the time necessary to perform the elements of the operation.

(2) *Subsidiary Time*—these usually being periodic elements which occur at regular intervals, such as the operator of a power press picking up a handful of pieces and placing them on the table of the machine, this perhaps taking place once for every 100 pieces produced. If the time necessary is 100 seconds for handling the pieces to the press table, then one second should be allowed on each piece.

(3) *Preparation Time*—this being the time necessary to get ready to perform the work, such as preparing the machine, gathering tools and reading prints. The total of this time should be spread over the number of pieces to be produced.

(4) *Personal Allowance*—the times necessary for the personal needs of the operator such as washing and toilet. This can usually be allowed on the basis of an allowed number of minutes per hour.

(5) *Fatigue Allowance*—the time for rest necessary to overcome fatgue in performing the work.

(6) *Contingency Allowance*—such as breakage of drills, sharpening of tools, etc., which may not occur whilst the study is being taken.

The basic time is built up of the actual operating time—that is, the time necessary to make the actual change in the form or shape of the article being worked upon, and the elements necessary for this performance. This operating time may be either :—

(1) *Completely automatic*—such as a lathe using automatic traverse when the operator has no influence on the cutting time.

(2) *Semi-manual*—such as drilling by hand where the operator feeds the drill, but where motive power is supplied to the tool and the tool is guided.

(3) *Manual*—such as chipping of castings, where both the guiding of the tool and the force applied are manual.

It is rather important to determine the operating time in relation to the basic time. The time necessary for any work to be performed is fundamentally the actual work time plus the time for rest necessary to overcome the fatigue incurred in its performance.

If then in the time study the operating element is automatic it is not sufficient just to ignore any allowance for fatigue. Here the operator has had a pause from actual work and so has a rest period to overcome some of the fatigue caused by the other elements comprising the basic time.

So in addition to ignoring any allowance on the operating element, it is also necessary to make a less allowance than would be necessary in either of the other cases, that is, manual or semi-manual, where no rest period does occur in the basic time.

The determination of the necessary allowance for fatigue can only be made by careful observations at various periods of the working day on different classes of work, and the results carefully compiled to find the fall of output during the day.

Contingency allowances also must be built up by observations taken in an overall manner on either various shops of a works, or if necessary on even various types of machine or operation.

The fatigue and contingency allowances having been made to the elements, the total time arrived at is the allowed or prescribed time necessary for the operator to perform the work so that with average effort he may perform that cycle for the whole of the day.

To complete the study, that is the constructive part of the study, the obverse side of the sheet is entered showing the operator's name, and notes on the conditions under which the study has been taken. The number of times each element occurs is also entered and the time extended to give the grand total of time allowed at the foot of the sheet. So far the purpose of the time study has been to set the time allowance for the operator.

Standards and Formulæ.

The next step is to construct the standards and formulæ from the results obtained. This can only be done by classification and recording of the elements, one method of which is to use a mnemonic

classification of the elements under various types of operation. Once standards are reached they should not be considered inflexible, but unless good reason can be found should be used in preference to actual times recorded, since they are the result of intensive recording and averaging, and are an excellent guide to the performance of operators. Formulæ can be constructed when the necessary information has been obtained for the working out of future time values. Standard element times are used for estimating purposes by building up synthetic studies and should always be reserved for comparison when the work is actually performed. Also, as shown previously, time study provides a sound basis for costing purposes, particularly with the tendency of increasing overheads, and as the general view now is that the main factor influencing these overheads is time, time study is absolutely necessary in any modern business.

In addition to providing the basis for costs, with properly organised time study we have the best possible measure of manufacturing efficiency, that is the hours of work actually produced.

Training for Time Study.

The qualifications and training necessary for time study work are largely a matter of opinion, but the following may be taken as a general outline.

(1) A sound knowledge of the industry in which the observer is engaged, as a man cannot take a study of work unless he knows the requirements of the process.

(2) Keenness of perception and an ability for detail. No detail however small should be beneath his notice.

(3) An ability to inspire confidence with the people whom he has to observe. This is very necessary, as there has, in the past, been a certain amount of suspicion regarding the methods used, and the workman can do a lot to aid the observer.

In training observers it is vital that they should be taught to split the elements in exactly the same manner so that standards may be produced, otherwise it is quite likely that the studies will be worthless apart from the operation for which they are made, and that, as shown previously, is only a small part of their use.

Conclusions.

Before passing to the second subject, time study can be briefly summed up :—

In dealing with time study we are dealing with a method, and not an exact science. Unfortunately we have not, outside elaborate laboratory instruments, any instruments which enable us to measure the amount of physical work done, or the fatigue incurred.

With the use of standards, and the tendency for an observer to study several workers on the same task, or for several observers to study one or a number of workers, valuable data is being obtained.

Perhaps we shall eventually have the instruments required, and time study will be on the basis of an exact science.

Motion Study.

In the earlier part of this paper it was shown how, in the build up of any job or process, the primary stage, that is the smallest element to which it can be broken down, is the element of motion. It is on these fundamental elements of all work that the principles of motion study are founded, and its attention focussed. No matter what the operation is it can be broken down to these elements of motion of which there are a limited number.

There is only one particular combination of these elements which can possibly be correct for performing a given piece of work. This, as Gilbreth said, is " the one best way of doing the job." The finding of this one best way is the purpose and aim of motion study.

Motion study is a method of analysing work in order to eliminate all needless, ill-directed, and ineffective effort, and its consequent fatigue. In any task the only part of the work performed which is of any use to employee or employer is the absolute minimum necessary to perform the task. Any surplus above this minimum is equally useless both to employer and employee. To the employer it means lower output and efficiency and to the employee it is effort wasted, since this surplus is directed to no useful purpose.

Like time study, motion study has a comparatively small history, as it was mainly the work of one man, Frank Gilbreth, also an American. His interest was first aroused when, in learning the art of bricklaying he found that no two men taught him the same method and that due to this there was a difference in their output of work. It was on this observation that Gilbreth formed his basic conclusion " that there is only one best way of doing work," and with this starting point Gilbreth along with his daughter carried out the researches which laid down the fundamental principles of motion study. This early work was of the laboratory type but to-day motion study can be applied simply and easily, at least in its broad form, without even any apparatus.

The basic principles of motion study can be divided into two groups, the main sections being: (i) The elements of motion; (ii) the law of motion economy.

Elements of Motion.

Firstly the elements. Of these there are seventeen, and though each may vary in time or effort or distance, they do perform the same function. These elements Gilbreth called " therbligs," which is, of course, his name reversed. They are :—

(1) Search.
(2) Find.
(3) Select.
(4) Grasp.
(5) Transport loaded.
(6) Position.
(7) Assemble.
(8) Use.
(9) Dis-assemble.
(10) Inspect.
(11) Pre-position.
(12) Release load.
(13) Transport empty.
(14) Rest for overcoming fatigue.
(15) Unavoidable delay.
(16) Avoidable delay.
(17) Plan.

Each of these therbligs has a symbol, and a colour, both of which are used by the analyst.

On analysing these therbligs it is easy to see that the only one in which skill is required and in which the work itself is actually done is the therblig *use*, and so is the most productive and at the same time the most difficult to master. The other therbligs are incidental to this and should only be permitted so far as they assist in increasing *use* to its maximum productivity.

Firstly, then, in the performance of any work the minimum number of therbligs should be used, and the search and avoidable delay should if possible be deleted. The therbligs *unavoidable delay* and *plan* should also be reduced to an absolute minimum.

In many cases the therbligs incidental to *use* can be performed by labour of a different class since they do not require skill, leaving the skilled operator with a minimum of incidental therbligs in the performance of his task.

Laws of Motion Economy.

The laws of motion and motion economy formulated by Gilbreth are :—

(1) Both hands should preferably begin their therbligs simultaneously.

(2) Both hands should preferably complete their therbligs at the same time.

(3) Both hands should not be idle at the same instant except during rest periods.

(4) Motions of arms should be in opposite and symmetrical directions instead of in the same direction and should be made simultaneously.

(5) Hesitation should be analysed and studied, its causes accounted for, and if possible, eliminated.

(6) Shortest time demonstrated in one part of a study should be used as mark to attain and reason for other times required in other parts of the study should be known.

(7) Number of therbligs required to do work should be counted ; for the best way is almost always a sequence of the fewest therbligs.

(8) The best sequence of therbligs in any one kind of work is useful as suggesting the best sequence in other kinds of work.

(9) Every instance where delay occurs suggests advisability of providing some optional work that will permit utilising the time of delay, if so desired, or of making fatigue study of the interval.

(10) Variations of time required for any single therblig should be arranged and causes recorded.

(11) Lateness of various parts of the anatomy as compared with other portions should be recorded.

(12) All materials and tools should be located within the normal grasp area. This is the area enclosed by the arcs, described by a full sweep of both arms without movement of the trunk.

(13) Motions should be confined to lowest possible classifications in order to reduce fatigue.

(14) Tools and materials should be located so as to permit proper sequence of therbligs. The part required at the beginning of the cycle should be next to the point of release of the finished piece from the former cycle.

(15) Sequence of motions should be arranged to build rhythm and automaticity.

(16) Hands should be relieved of all work that can be done by feet or other parts of the body.

(17) Tools and materials should be prepositioned as much as possible to reduce the search, find, and select therbligs.

(18) Gravity feed containers should be used to deliver material as close to the point of assembly or use as possible. This delivery point should be near the height at which it is assembled, in order

to eliminate any lifting or change or direction in carrying the parts to assembly.

(19) Ejectors should be used to remove the finished part.

(20) Use " drop delivery " whereby the operator may deliver the finished article by releasing it in the position in which it was completed without having to dispose of it.

Reviewing these laws, particularly 1, 2, 3, and 4, it is found the nearest approach to ideal is obtained when identical work is done with each hand. This is most nearly approached when assembling or making two of the same article simultaneously with each hand, and requires ambidexterity, and probably shows to its best advantage the application of motion study.

It is really surprising how quickly an operator can be taught to used the left hand, even though he may claim that he cannot.

Equipment and Methods of Micro-motion Analysis.

The cine-camera is the instrument of the analyst, and is usually of the 16 mm. type, having variable shutter speeds and using reversible film. It is generally necessary to use artificial lighting. employing two 500 watt floodlamps to give good modelling.

For the purposes of analysis the film is usually taken at 32 or 64 frames per second instead of the normal 16, so that slow motion is obtained when the film is projected. In the field of the camera is placed the micro-chronometer. This is a high speed clock, the disc of which is divided into 100 divisions, the finger performing 20 revs. Each division is then 1/2,000 of a minute and is known as the wink, and is the unit of time for motion study analysis.

The analysis of the film requires patience. The analyst runs the film through the projector several times to become thoroughly acquainted with the operation. He then proceeds to analyse each hand, by noting the start and finish of each therblig against the time shown by the micro-chronometer and entering it along with the approximate therblig on an analysis sheet. If the movements are complex it may even be necessary to examine the film a frame at a time to determine the start and finish of the movements and also to discover in what fatigue grouping the movement lies.

The next step is to make from this analysis a simultaneous motion chart, which is a graphic representation of the work performed by each hand, and if necessary any other parts of the body which are brought into play, drawn against a time scale. The use of each finger, and wrist and arm movements is shown by dividing the two main columns into sub-columns for each finger, the columns being continued only by the lines representing the digits in use. Against each movement is shown the therblig and the elapsed time.

By making this picture of an operation the analyst is able to

compare easily the movement of both hands at a given time, and is able to see where movements are wrong and where breaks and delays occur.

The analysis being complete, the next move is to build up a synthetic symo-chart of the ideal way of performing the operation, and to put this method into use by teaching the operator and correcting his faults. There should be no satisfaction until the time shown by the synthetic symo-chart is attained, as this chart does represent the time in which the work can be done. It may be necessary to re-film the job and modify ideas a number of times even, before the degree of attainment shown by the chart is reached. That, briefly, is the basis of micro-motion study.

The effect of applied motion study in the factory can be seen in the layout of the workplace. The special work trays to keep parts within the normal working area, the provision of drop delivery chutes, the prepositioning of tools, and finally the use of both hands simultaneously. It will also be seen that there is a general sense of tidiness about the workplace.

The use of both hands is very often thought to be only a matter of common-sense (but many instances could still be found where the old methods prevail), and it is only common-sense, but coupled with a sound knowledge of the principles of motion economy involved. For this common-sense method no apparatus is required, and very often it costs little or nothing to apply.

This does not mean that the camera and projector, and micro-motion study are not required. When an operation is of a complex nature and movements cannot easily be followed and recorded, it is absolutely necessary. This is not the only use of the camera and projector however. For teaching and demonstration purposes it has no equal. It can either be used to show one operator his faults, or can be used for demonstration purposes to make the entire organisation motion-minded.

To make the entire organisation motion-minded is the starting point of an increase of general efficiency, and leaves the analyst free to analyse where it is required.

The Process Chart.

There is another side also to this question of commonsense motion study, that is, the use of the process chart. In any manufacturing concern the ideal is to convert the raw material to the finished product in the quickest possible time, and with the greatest possible efficiency. The parts under course of manufacture may, during this period between raw material and finished product, travel hundreds or even thousands of feet, and of course, for every foot that the part moves work which is not really useful must be done. This; perhaps, is the best starting point for the application of motion study. For

this purpose a process chart is made, showing symbolically every operation, trucking and storage of the work, and can be if necessary drawn against a distance scale.

The making of a process chart will often reveal a surprising distance travelled, and can often be the means of removing hidden sources of hold up in manufacture. Its influence will be found in the layout of machinery and storage places, and will ensure that the work travels by the shortest possible route and with a minimum of handling.

Motion study should not be confined to the purely productive process of an organisation, but to office work, and in fact to the physical part of any work, for whether it is the assembly of a machine or the opening of envelopes in the office, the work is composed of the same elemental motions. It is equally important to do any of these operations in the most efficient way possible, and with motion study this can be achieved.

The Effects of Motion Study.

The effects of the application of motion study are seen in many directions. Its influence is seen in the design of tools. If the tool designer has a sound knowledge of the principles of motion economy he will keep them in mind in his designs, so that, in operation of the jig, movements are kept to an absolute minimum, that is, such as the jig being unlocked at one movement and the provision of foot ejectors. Its influence may also be felt in the design of the product itself. This does not necessarily mean that it will alter the nucleus of design, but if the designer keeps the principles in mind, he can influence the build up of the design, say, to make the assembly keep in line with the principles.

It is often asked what the effect of motion study is on the operator. Motion study teaches the operator the right way of performing work. It removes all the work which is useless to him and his employer, studies the fatigue incurred and finds the way of performing the work in the simplest way possible. With this increase in efficiency the operator enhances his own earning power, for efficiency is the keynote to high pay. It is found that the operators themselves are interested in motion study, and that the increased rhythm makes their task easier.

Conclusion.

Motion study should not be approached as merely a method of speeding up, but as finding the right way. It is obvious, of course, that if an operation is carefully analysed and all waste and unnecessary motion obviated, then there is inevitably an increase in output per unit of effort, and this after all is what is expected. We only

study jobs which we think are wrong, to endeavour to find the right way.

At the same time care has to be exercised on what jobs are studied, for to quote Lillian Gilbreth, " There is too much study of work which should be eliminated, not studied."

Finally then, it should be kept in mind that the generic purpose of motion study in *not* this speeding up, but as stressed previously, the endeavour to find the best way.

Discussion.

Mr. A. Sykes : I think Mr. Hall spoke very truly when he said the subject he was dealing with was perhaps one of the most controversial we have to deal with in the engineering industry, and perhaps the same remarks apply to other industries. The subject bristles with difficulties not only for the investigator, but perhaps more particularly, for the unfortunate individual who has to apply the "Time and Motion Study" after making it, to work of a similar character, the man we usually know as the rate fixer.

A great deal depends on the method by which this subject is approached as to whether we shall achieve success or otherwise. If we look upon it simply as a means of reducing the amount paid in proportion to the effort exerted, we may not go very far, particularly if we endeavour to speed up to an "unnatural" extent. If we speed up the worker in an "unnatural" way it is almost sure to have its reflection in some way or other—either undue fatigue or his useful working life reduced. He should be encouraged to work at the most suitable speed to suit his individual characteristics. The correct method to approach this subject is with the idea of improving methods and reducing fatigue. Mr. Hall referred to what is the right time to fix when we have taken a "Time Study" ; is it the shortest time, the average time or something else ? I think it may be there is more than one right time. The right time for one may not be the right time for another. In fixing the time, if one makes it too long it is a fact that very many workers tend to take longer than they should, on the other hand if the time set is too short slow workers get discouraged. A good time for one worker may discourage another. It is somewhat difficult to say what is the ideal time.

I would like to ask Mr. Hall whether he has had to approach the problem of having different grades of workers on the same kind of work—skilled journeymen in one case and apprentices in another. How does he grade times allowed to apprentices in relation to those of the skilled worker ? The same might also be said on the subject of "Motion Study." Mr. Hall referred to the question of rhythm. The type of "Motion" that suits one individual does not necessarily suit another. His object was to find the best motion. Is there a "best" motion ? What is best for one individual may not necessarily be the best for another. The shortest movement is not always the best, a circular sweeping movement in such a way that one motion follows on more easily from another is frequently better than a straight line which may be the shortest path between two given points.

It is quite clear that we cannot definitely say which is the best as applying to all workers, but I am quite sure we are all of us very grateful for what Mr. Hall has shown us. I think the motion pictures demonstrated very clearly what could be done and must form useful records. Mr. Hall has indicated that his primary object was to reduce fatigue and reduce effort rather than pull down times. If we reduce fatigue it is quite clear times will automatically come down and increase the goodwill of the worker. It is essential for the observers to keep the goodwill of the people they are working with, it is not a one sided affair but a partnership in which the worker increases his earnings and reduces fatigue whilst the employer has a large amount to gain in the saving of overheads.

Mr. Hall: Referring to the question of the right time. I am afraid that I must disagree with Mr. Sykes. There can only be one right time for a given class of labour on the same task. The assessment of this right time is, of course, the most difficult part of the time study observer's work. As regards the application of time study to skilled work. I must confess that we have had practically none of this to do, our applications up to the present having been limited almost entirely to unskilled labour—both male and female. There seems to be a great deal of controversy regarding the application of time study to skilled labour. The German school do not seem particularly keen on its application, whereas the American school would appear to claim that time study can be applied to any task. The question of the time allowed for apprentices is again one with which we have not had to deal, but I would suggest that the only way is to observe both a journeyman and an apprentice on the same job, and record the results so that a percentage can be fixed to be added to the journeyman's time, which is the real time, so that the apprentice will always be allowed this amount extra, which will of course vary with class of work. Mr. Sykes also asks about the shortest path of movement not always being the best path. Speaking generally it is, but at times it is found necessary to modify this or to even insert extra and apparently useless motions to preserve rythm.

Mr. Geo. Hepworth: I have listened with great interest to the lecture to-night. In my opinion it is mostly applicable to the handling and assembly of very small parts by unskilled labour. Taking automatic machinery into consideration, motion and time study has already been under consideration. There is a vast difference between the two applications. For instance, it is not vital to study motions or actions of an operator measuring plain cylindrical work by a micrometer, whereas to-day these are done by automatic sizing devices. I think if more studies were taken in the handling of materials, especially of small manufacturing parts, it would be

found to be a vital factor in the cost of production, especially in large commercial works.

Mr. F. Grover: The lecture has been one of great interest although, because of its more appropriate application to mass production, some of us may find little of direct application to our own work. It spite of this we can learn a great deal by assimilating the methods advocated. One of the lessons which might be taken to heart by the " odd job " man as distinct from the mass producer is the implied inculcation of tidyness running through the lecture. One of the diagrams shown illustrated the range of reach of an operator. It suggested to me the importance of having one's bench tools well placed within easy reach, each with its own location, so that the worker avoided the feverish search for each tool in turn. I recently had a homely illustration of the way in which discontinuity of order could upset one's work and peace of mind. On returning from a trip to South America I was doing an urgent domestic job in my garage and quite automatically I reached forth to the accustomed hook for my cutting pliers. They were not there. The borrower in my absence had failed to replace them and they were found in a drawer entangled and obscured by innumerable pieces of odd bits of string. We have heard some interesting things to-night in regard to the technique of making accurate timing observations with the cine-camera. One of the technical terms introduced by the lecturer might well be remembered by a young man confiding in his best girl, and that is the name given to the period of time comprising one two-thousandth part of a minute. It appears that this is known to the timing experts as a " wink " whereas I should like to point out that philosophers have been prone to regard such brief intervals as the mere conflux of two eternities.

Mr. E. Drake: Whenever I hear other time study men talking about their work, the thing that strikes me is what an easy sort of job they always seem to find to do. They usually seem to come across a cycle of about five minutes consisting of a dozen or so elements, which always occur in regular order, and there never seems to be any variation in the quality of the material they are working on. My own experience is rather different from this. The longest cycle I have ever had to study lasted for some thirty hours, and I don't know how I could be expected to watch five or six cycles of this job before starting the study.

There are all sorts of things I would like to take up with Mr. Hall, but I will just choose two points. The first one concerns the skill and effort rating. Mr. Hall showed on his form a separate rating for every element of work. I have used that method, but I have rejected it because I do not find it possible to make any decision as to variations in effort between one small element and another with

which I can be satisfied ; so at present I am rating the skill and effort of the operator on the whole job, and only taking into account variations between elements when they are really important.

The other point I would like to raise is the question of fatigue allowances. Mr. Hall explained that these could be fixed by taking several studies of different kinds of operators at different times of day. I would like to know whether Mr. Hall has really done this in practice, or whether he has merely taken certain standard percentages from the same book from which he got the study form.

Mr. Hall : Mr. Drake is quite right in saying that an observer cannot be expected to make several studies of a cycle lasting thirty hours, nor can he be expected to watch several cycles before commencing the study. A somewhat different technique is required. It is obvious that the ordinary time study sheet would be useless for this purpose, a sheet of foolscap size, say, with the elements entered below each other should be used, and the observer must start at the beginning of the cycle and make all his observations and notes whilst the work is in progress. I must confess to having skipped one part of my paper regarding rating, as I intended to say that an overall rating could be, and is much used, in which case it is known as blanket rating. The use of either method is purely a question of choice or is dictated by circumstances. Where the elements are very small I agree with Mr. Drake that element rating is extremely difficult and at least impracticable, if not impossible. Mr. Drake also questions fatigue allowances. We have done a certain amount of work on particular classes of machines, particularly small machines, but have not yet been able to carry out our studies to the extent we should like, as our work covers such a wide range of engineering processes. Where we have no data we use a $12\frac{1}{2}\%$ allowance, which is equal to one hour per day approximately, but we do vary it definitely in accordance with the relation of the operating time to te basic time, where the operating time is purely automatic.

Mr. F. Lightowler : Probably I have missed one of the lecturer's points—possibly he has been instructed to make things as simple as possible for us—but one of the vital points in building up the rate was the factor with which the selected time was modified so as to give an allowance for fatigue and I am not clear as to the means he uses to obtain that factor. I understood him to say it was obtained when he had accumulated a sufficient bulk of studies. If that is correct it means that these studies are wasted but for this one purpose—since no fatigue factor is available. This factor is an important point in the use of the study and I should like him to go more fully into his methods of obtaining it—if I am not asking him to give another lecture.

Mr. Hall : Mr. Lightowler has raised, I think, the most difficult question of all. If not requiring another lecture, it would probably

require another discussion. Time study is not limited to fixing a speed for a certain operation, and to arrive at levelling factors you have to make a large number of studies on various classes of work, to endeavour to assess, and it is purely assessment, what constitutes maximum and minimum efficiency on each class of work. For instance, the graph which was shown for gap gauging was the result of two or three hundred studies of that particular class of operation and many of these were never used apart from assessing an average and maximum and minimum efficiencies for levelling factors. I think I have stressed all along that time study is a method and not an exact science, as we have not the instruments to make the measurements we would like to make, so that the final results must be based on the assessments of one or a group of observers.

Mr. J. D. Scaife (Section President, in the chair): This matter of mass production has been of particular interest to me for thirty years or more, and whether Mr. Hall has been more fortunate than I, I do not know, but my particular difficulty in this matter has been in the matter of skill,—the increase in skill on the part of the operators through the years. Mr. Hall seems to have pre-supposed a certain amount of skill on the part of the operator at the outset being fixed, and the improvement was only in the appliances. I do not know whether I have missed something out of the paper, but I should like to give an instance of a particular operation, which was at one time under my care, and that was the putting of sewing machine needles in one direction into a box. When they came from the last operation they were all mixed together and it was a girls' job to put these needles all with the same ends—the thick ends of the needles—together in one row. The only appliance used for that purpose was a piece of strip steel and the girls improved in their skill and the speed at which they could do that job for years and taking the first week's output and the output at the end of the year, probably like 100 times more in the end. Mr. Hall's motion study would have been unable to form any idea as to the ultimate output of that operator. There are certain operators more gifted or adaptable than others and with the best intentions in the world, and after a long and continued process of elimination the output of the best operators was close on 200% more than the worst. I do not know how Mr. Hall would apply himself to problems like that.

Mr. Hall: The first thing to realise in time study is that you must not study the operator for speed setting purposes until it is ready for the observations. You should, however, take studies to plot the increase in efficiency. When the work is purely manual such as in the case which Mr. Scaife has raised, a fairly long time is necessary before a speed is fixed. Even so, if results show that efficiency is still rising and yet it is necessary to fix a speed for an incentive, then this must be in the nature of an estimate. But in this case the

big thing is, that if you have fixed a speed and both the observer and management are satisfied, then that speed should stand whether an operator increases output by 100% or not. The observer must have the complete confidence of both the management and the employee. If such an increase in efficiency did take place, then providing that it is recorded against the original studies, you have gained more knowledge for future use.

MR. T. W. SYKES : Mr. Hall is particularly fortunate in being in a position to apply time and motion study to mass production as in my opinion, mass production work lends itself particularly well to this problem. I should like to know how Mr. Hall would apply time study and motion study to a jobbing works where almost every job differs and operations range from a few minutes to hundreds of hours. For example, how would he proceed to apply time and motion study to, say, hobbing a large gear which may take anything from 300 to 400 hours to cut ? Another point is, how does Mr. Hall overcome difficulties with the operators when these methods are introduced ? I have seen time study a few years ago where it gave a great deal of dissatisfaction in many cases, due primarily to the fact that the observers were not properly trained. In fact, apprentices were employed as observers and the difficulty was that they had to try to observe various operations and movements when they did not know why it was being done, and what was to be done next. I think one of the first essentials which is necessary is that the observers should be qualified, and know the job they are observing. I should like to know if Mr. Hall experienced any trouble from a labour point of view.

MR. HALL : The application of time study should never be carried beyond its economic limit. In the case which Mr. Skyes has suggested, I think the method to be used would be on the estimating basis as I pointed out in my paper. It would cost as much or even more to carry out the time study than it would to do the job, but time study could be used as a basis for the estimates. The application of motion study should, of course, only be carried out in its broadest form. That is, tool racks provided on the machines, and materials and equipment positioned near to the points of requirement, and the operators taught to replace the tools where taken from. We have had little trouble regarding the introduction of time study, but this may or may not be due to the fact that we have very little dealing with skilled labour. The studies are, of course, always taken openly and as Mr. Sykes has said, the observers know the work with which they are dealing.

CAPT. L. J. SARJEANT : I am definitely interested, of course, in anything which improves efficiency and Mr. Hall in putting these points showed that the aim of time and motion study is to get the very best way of doing a job, which is, of course, what we mean

by efficiency. I am, however, very much with the last speaker on the question of labour, and I think that the reason why Mr. Hall has not had labour trouble is, because his labour was mainly girls and women, and probably people who had not done any sort of work in a factory before. I am interested in this point because we have this difficulty at the moment, in that where we are trying to introduce these more scientific methods into a certain shop there is a definite re-action against stop-watch time study methods. My own reasoning is, that where these conditions exist there can be no short cut to their adoption, it can only be a long and slow process of education of the workers and convincing them of the squareness of the deal which the employer is trying to give them. I should value very much any advice which Mr. Hall can give me on his experience, and also any information which anyone else can give me.

MR. HALL: I agree absolutely with Capt. Sarjeant regarding the application of time study to skilled labour, and that it must be a long and arduous process. I do think, however, that the best way is to impress them with the fairness of the methods employed and if necessary to let one of the workmen be with the observer whilst the study is taken. Even so, predjudices no doubt do a lot to retard us in this direction, but I feel that with education in the proper uses of time study the skilled men will accept it with much less trouble.

COLONEL GEO. BRAY: I have very great pleasure in proposing the vote of thanks to Mr. Hall for a very interesting and enjoyable lecture. I should have liked to ask a number of questions during the lecture, but this was too good an entertainment to be interrupted in that way. I thank Mr. Hall very much.

MR. F. R. SMITH: I have great pleasure in seconding the vote of thanks to Mr. Hall. I have enjoyed the lecture, but I am somewhat disappointed, in that the subject has been interpreted as only affecting girls. Surely, firms with the reputations of the ones who do use time and motion study have long ago applied it in the more lucrative quarters and not confined it to the sphere of labour which averages a wage earning capacity of say 15s. or 20s. per week. I think the references that have been made to the possible application of time and motion study to the skilled trades are on the wrong basis. I believe that time and motion study has been applied to the skilled trades for a very large number of years, principally by the foremen. The percentage of the foremen's time necessary to ensure that the men work on commonsense lines is small. It is true that a growth has taken place of factories in which small assemblies are carried on in very large numbers, and in such factories it has been found economic to engage experts on this subject. As has been generally indicated, time study represents an alternative to the proverbial rate-fixer's "guess" and motion study aims at commonsense methods of manufacture. I think that it is good to have the

opportunity of listening to professional time and motion men who deal with small assemblies in mass-production factories, and that out of this privilege it is possible for foremen of less fortunate works to gain a knowledge of the principles which experts evolve. It must be admitted that these principles can help foremen to increase the efficiency of their skilled men. For this privilege we thank Mr. Hall.

MR. HALL: I would like to reply to Mr. Smith's remarks. Firstly, he is hardly correct when he says that female labour earns about 15s. to 20s. per week in a modern factory; it is nearer double that amount. Secondly, I have not stressed at any point in my paper that we have only girl labour to deal with and on which to apply motion and time study. We have about even numbers of male and female workers and apply it to both. It is quite likely that motion study principles have been applied in the skilled trades by the foremen on a commonsense basis, but at the same time I still think that a lot of good would be done by educating these men in motion study principles. Finally, may I say what a very great pleasure it has been to come to Leeds this evening. I rather expected that the discussion would develop into a "Battle of the Roses" but can assure you that I really appreciate the interest which has been shown.